

Neuro-Muscular Structures in the Heart.

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The fundamental fact of the existence of a muscular connection between auricle and ventricle in the mammalian heart was established in 1892 (5, 6). The details of the particular connection first studied were worked out during the years following (1, 3, 7, 8, 13, 15), and attention was directed so completely to the auriculo-ventricular bundle itself that additional ties between auricle and ventricle at other points remained relatively neglected. Partly in result of this, though partly in result of experiments which have been perhaps imperfectly understood, an impression has gained ground (2, 14) that apart from the originally described auriculo-ventricular bundle there exists no other conducting path capable of transferring the state of activity from auricular muscle to ventricular, or *vice versa*. This impression has, indeed, been put forward as an actually ascertained fact (10).

For some years, however, a mass of facts has been accumulating difficult to explain on the supposition that the conduction between auricle and ventricle consists of one single path alone. The facts can, on the other hand, be explained satisfactorily if there be granted the existence of an auriculo-ventricular connection which is multiple.

These facts have become known partly as the result of clinical experiences and partly as the result of direct experiment, and are so definite that it is necessary for any satisfactory theory of the cardiac mechanism to take account of them.

The clinical experiences referred to fall into two categories:—

A. Cases in which the auriculo-ventricular sequence was found to be normal, though the bundle was destroyed (4, 11); and

B. Cases in which the auriculo-ventricular sequence was abolished, though the bundle was intact (4, 9, 12).

There are in the literature several cases illustrating each of these conditions, and the conclusion is becoming more and more firmly established, that the normal auriculo-ventricular sequence may exist with a destroyed bundle, and that the sequence may be disturbed, or abolished, the bundle remaining unaffected.

In other words, it appears that the auriculo-ventricular bundle is not the only path by which the functional connection between the auricle and ventricle may be established, and that "the co-operation between the auricle and ventricle is not necessarily dissolved because the auriculo-ventricular bundle has been put out of action" (4).

The experimental evidence to which reference has been made is at present unpublished, and was first brought to my notice by Prof. Leonard Hill, to whom I am indebted for permission to refer to it. I have recently repeated the experiments, and can have no doubt as to their real significance.

The evidence is of the following character:—

If in the beating heart of a mammal the anatomical connections between the left auricle and left ventricle are severed, and the section is carried through the septum also, thus leaving only the right ventricular wall attached to the auricle, even under these circumstances co-ordinated beats pass over the auriculo-ventricular junction, the ventricular contraction following the auricular in its proper sequence.

With such clinical and experimental evidence before us it is idle to assert that no conducting path exists other than the well-known and well-defined auriculo-ventricular bundle, and the question is no longer "Does a connection exist?" but "What is the nature of the connection?"

It may perhaps be recollected that as long ago as 1892 (5, 6) I described the existence of a connection in this situation, viz., between the outer wall of auricle and ventricle. The importance of the recently-described septal connections overshadowed this other observation, however, and its significance was not appreciated. It was only when the fact that the auriculo-ventricular bundle could be destroyed without abolishing the co-ordinated action between the chambers that the importance of additional conducting paths was brought into prominence.

During the past few years my work on the human heart has shown that there exists a mechanism which may perhaps help to elucidate the manner in which these hitherto imperfectly explained transferences of activity are brought about, and although the details have not all been worked out, it may perhaps be of use to place the facts on record.

It is well known that in a series of sections made through the auriculo-ventricular junction an outstanding feature is the large number of nervous structures present. It is no uncommon thing to find from 20 to 30 nerve trunks cut across, some 50μ to 100μ in diameter, most of them lying in the fat and connective tissue of the groove, whilst in addition to these there are trunks of large size lying amongst the muscular tissue, and apparently derived directly from those in the groove.

In close association with these nerve fibres there exist nerve cells, occasionally single, often in groups of two or three, sometimes in large numbers. Many of these cells are of great size, and in other particulars remarkable in appearance. They are very markedly irregular in their distribution, and may be scanty even where nerve fibres are abundant, whilst in other situations they may be numerous.

The exact function of these nerve cells is open to conjecture, and it is therefore of interest to find them associated with other structures, the connections of which may throw light upon their mode of action.

The structures referred to are found lying in the connective tissue between the auricular and ventricular muscle, and are of a type hitherto undescribed in the heart. They consist of an elongated body, the first indications of which in any series of sections is the appearance of two or three nerve fibres lying amongst the fibrous tissue. In sections passing directly from auricle to ventricle and taken vertically to the surface, these fibres are as a rule cut transversely. If the series be followed the number of fibres in the group is seen to increase, until ultimately a large number are present.

At this point some resemblance to an ordinary nerve trunk is presented, and the diameter of the structure may be about $170\ \mu$.

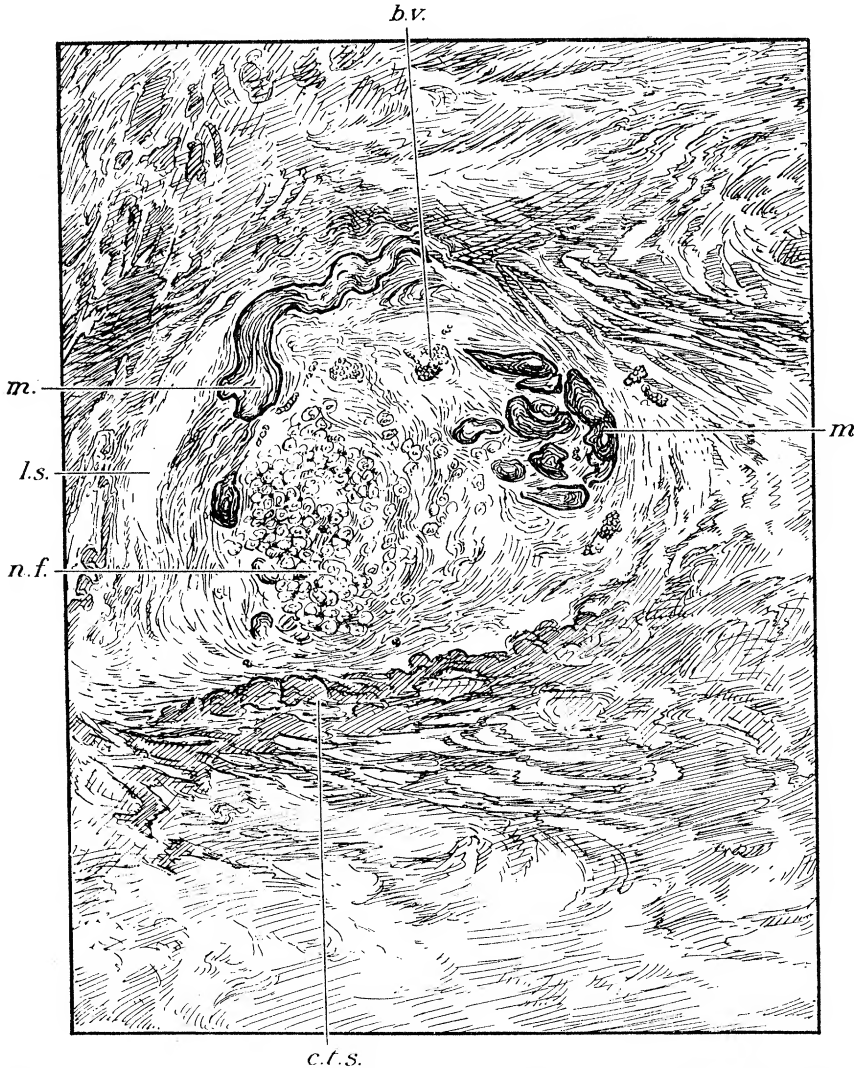
The constituent fibres vary a good deal in size, ranging from about $3\ \mu$ to about $12\ \mu$ in diameter. A number of measurements gave the average diameter of the most numerous fibres as about $7\ \mu$. Connective tissue of the fibrous variety is present in the bundle, but is principally developed at the periphery, where in the greater portion of the length of the bundle, a definite sheath is present, of considerable thickness, and composed of many layers with large lymphatic spaces lying between them.

If the bundle, for the structure has now assumed the form of a bundle, be followed further, a new constituent will be noticed to have made its appearance. This new constituent is muscle, and it generally appears as a small mass of tissue which stains more deeply than the rest of the bundle, and is readily distinguished from the other constituents present.

The muscle, after its appearance in the bundle, is generally to be found as a fibre running longitudinally, or winding amongst the other tissues, and showing a sharp differentiation into the darkly staining sarcostyles, and the lighter sarcoplasm. The latter is generally arranged at the centre of the fibre, whilst the sarcostyles occupy the periphery.

One muscle fibre having appeared, others are soon noticeable, and the number increases until a considerable portion of the bundle may be occupied by muscular tissue.

At the same time that the muscle becomes prominent in a bundle it may be noticed that a very large increase in the blood supply has taken place, and that, instead of the occasional small vessel observed at the commence-



Transverse section of structure lying in the connective tissue between the auricle and ventricle of human heart. $\times$ about 300. *c.t.s.*, connective tissue sheath; *l.s.*, lymph space; *b.v.*, blood vessel; *n.f.*, nerve fibres; *m.*, muscle. The general relations of parts only are shown, minute detail being for the most part omitted.

ment, a rich supply of blood is brought to the bundle by vessels of considerable size, and distributed through its substance. It may be stated generally that the blood supply is found to be most abundant in those

situations where the muscular tissue forms a constituent portion of the bundle.

With regard to the character of the muscle fibres which are found in the bundle, these appear to be of two kinds. Where the muscle is well represented some fibres will usually be found to resemble the tissue present in the neighbouring chamber of the heart. Others, however, are of a different type, and appear as large pale fibres, with but few sarcostyles, those that are present being grouped around the periphery of the fibre.

If the series of sections be followed further it will be found that the bundle, which at first may be at some distance from the muscle of the heart chamber, gradually approaches this latter, whilst at the same time some of the large pale fibres alluded to as being present in the bundle will be observed to be making their appearance also in the auricular or ventricular tissue, and, after a time, a definite exchange of muscle fibres on a large scale will be observed to take place between the auricle, or ventricle, and the bundle. Fibres which are apparently normal auricular or ventricular tissue approach the connective tissue, pass through as a definite mass of tissue, penetrate the connective tissue sheath of the bundle, and come to lie in its interior. In many cases the amount of muscle entering the bundle in this way is considerable, and much of the tissue is indistinguishable from ordinary cardiac tissue. Some, however, is of the character already described, consisting of fibres with clear centres and sarcostyles scattered around the periphery, and, though smaller, presenting some of the characters of Purkinje fibres.

It follows from this description that the amount of muscle present in the bundle varies considerably from place to place, and, moreover, that the character of the muscular tissue varies also, being sometimes similar to auricular or ventricular tissue, and having similar staining properties, and sometimes pale fibres containing much faintly staining sarcoplasm with comparatively few darkly staining sarcostyles.

The nerve fibres which form so important a part of the structures described are of various sizes, from 3μ to 12μ . They run, as a rule, a longitudinal or somewhat winding course in the bundle, and may be demonstrated to be connected at various points with the nervous structures lying in the fat at the auriculo-ventricular junction. They may also be traced leaving the bundle at various points, and passing away through the connective tissue towards the neighbouring tissues.

From the description which has been given it is apparent that the structure which has been described presents itself as an elongated body of different diameters at different parts of its course, and therefore of a conical

or fusiform shape, into the composition of which both nerve fibres and muscle fibres of two distinct varieties enter, surrounded by a distinct connective tissue sheath in which large lymphatic spaces exist, and being abundantly supplied with blood. Further, that these structures can be shown to be connected with the muscular tissue of the auricle or of the ventricle on the one hand, and with the nervous structures lying in the auriculo-ventricular groove on the other.

It will be at once apparent that the structures described have many points in common with the neuro-muscular spindles found in skeletal muscle. The association of nerve and muscle fibres in a definite structure, the modification of the muscle fibres, the general shape, even the connective tissue sheath with its lymphatic spaces, all recall the structure of neuro-muscular spindles.

And it may be that, just as the structure of the two organs is similar, so also are their functions. In the neuro-muscular spindles of skeletal muscle we see organs destined for the reception of impulses from the muscle fibres—impulses which pass to a centre consisting of nerve cells and throw it into activity, *i.e.* the organ is a receptive one and functions as a part of a reflex arc.

In the neuro-muscular structures described we see organs which from their structure and connections may well function as receptive organs, which may well be roused to activity by the muscle, and transmit impulses, it may be, to the local centre, *i.e.* to the nerve cells in the auriculo-ventricular groove.

And, further, if this is so, it is difficult to avoid the suggestion that we see here, as yet imperfectly described and obscure in some of its workings, a local mechanism whose function it is to place in communication the various chambers of the heart, and to correlate their activities—a mechanism consisting of receptive organ, afferent path, centre, efferent path, and distributing organ, and constituting a local reflex arc, which may perhaps exhibit only an occasional activity, the co-ordination of the cardiac rhythm being, as a rule, provided for by the muscular connections of the auriculo-ventricular bundle, but which may be capable of controlling that co-ordination when the bundle is no longer perfect.

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